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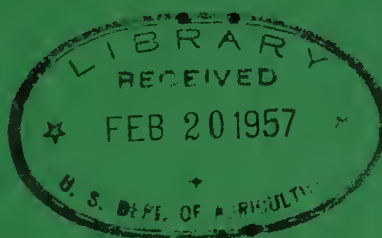
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FOREST SOIL PROBLEM ANALYSIS  
ON THE CROSSETT AREA

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ON THE CROSSETT AREA

The territory served by the Crossett Branch of the Southern Forest Experiment Station comprises northern Louisiana and southern Arkansas, west of the Mississippi Delta. The "Crossett area" to which the following discussion refers is somewhat more limited; it excludes the most westerly and southerly counties, where no observations were made.

The area has a growing season of about seven months and an annual precipitation of 45 to 50 inches. Rainfall distribution is somewhat irregular, and summer droughts are common. Physiographically the area is part of the great Southern Coastal Plain. It is composed of uplifted old marine sediments, varying from gravels to clays and rarely calcareous. The topography ranges from nearly level flood plains, terraces, and undissected uplands to undulating or rolling slopes. Accordingly, the soils are normally well weathered and deep, usually medium to heavy in texture except at the surface, and pass into unconsolidated substrates of either similar or different texture. The soils of level and gently sloping areas often show evidence of impeded drainage. Apart from the alluvial areas, the soils are generally low in mineral nutrients and organic matter (14, 31), <sup>1/</sup> thus presenting additional difficulties to agricultural use.

The history of agriculture has been one of slow and limited development, as exemplified by Census data for Ashley and Grant Counties, Arkansas: In 1870 the area of improved farm land (crop and cleared pasture land) composed only 10 percent of Ashley County and 3 percent of Grant. During the next forty years the areas expanded to 18 percent and 11 percent, respectively. Subsequent change was slow, for by 1950 the area of crop and pasture land had increased to only 22 percent in Ashley County and remained at 11 percent in Grant. The areas actually in farm ownership are materially greater (38 and 21 percent, respectively) since they include considerable woodland.

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<sup>1/</sup> Underscored numbers in parentheses refer to Literature Cited, p. 21.

The total area cleared was greater than the above values suggest. Stands of old-field pine indicate that land abandonment has been common in the past. The net area figures tend to conceal a continuing adjustment of agriculture through both abandonment and the greater use of the more suitable land.

Although logging accompanied the initial land clearing, the principal logging came somewhat later. For the most part it did not result in denudation and hence a very large percentage of the land either remained in or soon returned to forest, giving rise to a variety of age classes and cover type differences.

It seems quite certain that well over half of the area will find its maximum utility as productive forest. Already, however, the development of forest practice is outrunning the knowledge of the productivity and rational management of these lands, and greater demands for soils information are certain. Except for exploratory studies, relatively little is known about the soils of the area, and still less of their response to past events and to intensive management. Differences in productivity are sometimes associated with physical properties of the soils, but in certain instances adjacent stands differ greatly in site index for reasons not yet apparent. It is under these conditions that a program of forest soils investigation is to be undertaken. As will become apparent in the following pages, the contemplated program would be limited, at least initially, to upland forest types. Its scope would be modest, its purposes pragmatic. Accordingly, this analysis is in similar terms.

The attention to possible site deterioration results from a concern expressed by many foresters--a concern which may be unfounded but which will be influential in the absence of adequate evidence. The most rewarding experimental approach, however, is through a knowledge of the basic soil factors affecting growth and of their possible modification for better or worse.

## GENERAL

The nature of a forest soils research program for the area is affected by four general conditions: 1. --the favorable conditions for growth and utilization, 2. --an emphasis, in the uplands, on a few rapid-growing species amenable to management, 3. --a continuing increase in forest management intensity, and 4. --relatively little concern at present with ancillary uses of forest land, as for grazing or watershed protection.

Although the upland soils did not favor agricultural development under the conditions of the past, for the most part they are well suited for species (such as pine) with low fertility requirements. Because of late and limited land clearing, the area as a whole has escaped many of the soil and watershed problems so common in the long-settled regions of the Southeast.

The principal commercial species of the upland, loblolly and shortleaf pine, are valuable, rapid in growth, and responsive to treatment. These circumstances, together with accessibility and markets, have made investments in forest management profitable. Some of the bottomlands appear to offer at least as great management potentialities, as yet largely unrealized.

Adoption of forest management and the intensification of practices on managed lands have progressed rapidly. Moreover, both the present rate of change and the indications from silvicultural research point to intenser management in the future. It appears that this will call for greater manipulation of stand characteristics and environment, in the interest of wood production, than was formerly considered feasible.

To date, physiography and past land use have minimized any emphasis on watershed problems of non-agricultural lands. There are three aspects that may provoke discussion sometime in the future: The over-all effects of repeated fires on watershed values have not yet been evaluated, although the local effects of any one fire appear small. Similarly, the extent to which forest management practices may be capable of affecting runoff or water storage are unknown. Finally, although the area of abandoned farm land reverting to forest use is relatively small, its characteristics may be locally important in watershed behavior. These aspects may call for attention in the future, although at present their significance appears much less than in many other areas.

## OBJECTIVES

Thus the immediate objectives of forest soils research in this area should relate to productivity for timber growth: how to evaluate it, maintain it, and, if possible, improve it, within the framework of present and anticipated management conditions. Future management intensity will determine the interest in altering site and should not be underestimated.

It will be necessary, of course, to have an understanding of the natural processes in soils and the limitations they impose. It would be a mistake, however, to overstress the "naturalistic" approach to soils problems or the reliance on undisturbed natural conditions as an ideal, however useful such a datum may be on occasion. To study in detail the vast array of separate organisms and factors acting upon the forest is clearly hopeless. Instead, the main research effort should be confined to the processes which appear most likely to affect tree growth significantly. The success of modern agriculture rests in part upon the ability to discover and efficiently overcome the factors limiting crop growth.

The emphasis on productivity does not mean neglect of other considerations. Advances in the understanding of tree requirements must accompany productivity investigations. It is not unlikely that attention may have to be given to pathological problems involving soil factors. The necessary studies of soil moisture and physical characteristics will be useful also in appraising watershed values.

## CLASSES OF PROBLEMS

The foreseeable forest soils problems can be grouped into four general classes. These represent investigative approaches and are not mutually exclusive; often questions within one will relate to those in other groups or depend upon them for full solution.

### I. Tentative Site Classification

There is an immediate need for means of classifying productive capacity for pine other than by site index measurement. A basis for evaluation is often lacking on cut-over or open land, although elsewhere in the area site index is known to vary from below 60 feet to 120 feet. Quite evidently rational estimates of growth, land values, and the justifiable investments in planting or management depend on some appraisal of productive capacity. The land manager cannot operate "site unseen" and attain the most profitable intensity of management.

The evidence to date suggests that a satisfactory method based on soil characteristics can be developed (10, 13, 16, 18, 25, 36, 46). Turner in Arkansas (37-39), Chandler and others in Texas (5), and Coile and his students in the Southeast (8, 17, 33) have demonstrated relationships between site and observable soil features, and observations within the Crossett area agree.

To put such relationships into usable form will require numerous parallel determinations of growth and soil characteristics, and the resulting guide will be subject to revision as experience develops.

It is clear that a simple classification scheme to be used by foresters with little soils training would have wide applicability and is worth considerable generalization to obtain. Such a system, so used, may not be satisfactory for all classification purposes. The variety of profile types within the area (38, 39) is not conducive to discovering a guide that is at once very precise, simple, and fool-proof. Once the features of significance are known, however, there appears no reason why skilled surveyors should not be employed for detailed classification or mapping of forest land wherever such intensity is justified. Consequently, the product of the classification system may be two systems, at different levels of complexity and precision for different users. Possibly the work can be related to conventional soil types, thus facilitating the use of existing information.

In addition to its immediate utility, the field work to devise a classification system will provide a thorough acquaintance with the soils and soil problems of the area. Possibly supplementary information about the relations of soil to other species, to hardwood competition, and to wet weather trafficability may be obtained as well. Although the emphasis will be on getting a workable "system," a full consideration will not overlook the assumptions underlying the use of site index nor the fact that forest management must be based on more than predicted height at age 50. Differences within a single site class with respect to form, competition, ease of management, terrain, etc., may be considerable, especially within the lower classes.

## II. Site Deterioration

Management programs usually assume a stable level of soil productivity. The possibility of certain management practices causing a reduction in site quality has been frequently discussed. Comment has centered about the effects of fire and the reduction of hardwood species in favor of pine. A secondary consequence, soil compaction by wet-weather logging, also warrants attention.

The likelihood of reducing soil fertility through continuous wood removal does not seem very great. The possibility was investigated by Europeans (26), who found the annual losses relatively small and presumably offset by natural additions and the weathering of soil minerals.

An annual growth and removal of 110 cubic feet per acre of loblolly pine would amount to about 2 tons of dry wood, containing 6-8 pounds of nitrogen and much smaller amounts of other nutrients except calcium. Additional amounts would be included in the bark, but the totals seem sufficiently slight to be disregarded in the first consideration of site deterioration.

See  
p 18-19

Continuing small decreases in soil productivity over large areas would be serious, but to date such decreases are no more than matters of speculation. At present, site deterioration must be considered only as a class of possible effects, rather than a demonstrable problem. The term is a loose one and in the following pages it refers only to changes in soil properties--physical, chemical, and, in part, biological--under forest cover that reduce yield, either through retarded growth or accelerated mortality. (Management may increase the hazards from insects and pathogens when it reduces the proportion of non-susceptible species or increases the numbers of a susceptible species on an unfavorable site, but such hazards are not chargeable to soil changes.)

To begin a large-scale investigation of such a vague problem would surely prove inefficient. It seems better to start with exploratory studies that are limited to specific and readily measured effects, such as the influence of single burns on runoff, the weight and nutrient content of organic matter consumed by fire, etc. The results from such studies will define the problem better and indicate the magnitude of the variables. In addition, it would be well to consider the following propositions: 1. --the existing literature provides no applicable information except that in the case of fire the immediate consequences on these soils must be slight; 2. --the object is to determine the direct effects on soil productivity and watershed values over reasonably long periods; the application to management may involve additional considerations outside the scope of this study; 3. --if the practices in question significantly affect site quality, then the effects must be measurable or readily inferred from comprehensive basic data; 4. --regardless of theoretical considerations, if the assumed changes in productivity are not going to be of measurable significance within the next 50-100 years, they can be ignored for the present.

*what measure ?*

## II, A. Hardwood removal

The major question is whether reduction of the hardwood component of these mixed stands, by fire or TSI measures, will ultimately reduce soil productivity for pine. Such concern in the American literature arises in part from German assertions about the effects of pure

spruce on the soil, although the later writings of Wiedemann (26, p. 475) actually discounted many of the statements still cited. It is remarkable that European views on this subject should have received so serious consideration--outside of northern United States--in view of the wide differences in species, soils, and climate.

Not at all remarkable.

Evidence bearing directly upon the problem of growth effects is limited and so opinions are numerous. In considering these the particular conditions of the area must be borne in mind; that is, the soils are generally deep, medium to heavy in texture, usually uneroded, and with only slight litter accumulation. Complete eradication of the hardwoods is unlikely and understory shrubs, such as dogwood, will probably remain abundant despite TSI. The solid pine canopy often found in plantations or young stands does not persist in saw-timber stands.

The place of hardwoods in the rehabilitation of old fields receives mention later (III, C); the following refers to the relatively undisturbed forest soils. Discussion of hardwood admixture seems to revolve about 1. --the larger quantities of plant nutrients returned to the surface by hardwoods; 2. --the effect of hardwoods on litter decomposition and the physical properties of soil, and 3. --the greater stability of mixed stands when subjected to disturbances.

Nutrients in hardwood litter. --The leaf fall of most hardwoods, and certain conifers such as eastern redcedar, returns more calcium to the soil than that of pines (26, 29). With respect to nitrogen the evidence is contradictory and soil supply is probably confounded with species (6, 29). Among the hardwoods themselves there are marked differences in calcium content. Dogwood and hickory, for example, contain two or three times as much as sweetgum and most of the oaks. As an illustration of this, and of understory effects, the surface soil beneath 70-year-old pine with a dogwood understory was reported by Coile (7), to be much higher in exchangeable calcium than that beneath mixed oak stands. In other instances as well, chemical changes in the surface soil have been associated with calcium content of the leaf fall (2, 4, 32) and it is rather generally assumed that the high-calcium species aid in maintaining the base content of the surface layers (26).

Nevertheless in many regions highly coniferous stands have existed for several generations without serious reduction in yield (26, pp. 475, 477). The requirements of the species and the long-term contributions of the deeper soil layers must be considered along with possible surface changes in fertility.

This can not be proven.

Finally it should be remembered that even in the absence of understory effects the differences in calcium content being discussed range from less than 50 to a maximum of 200 pounds of ground limestone per acre per year. If the merit of a mixed stand depended chiefly upon the additional calcium it might well be supplied artificially at a cost less than the loss of pine growing-space. Thus this aspect of stand mixture must be resolved into the effect, if any, of greater base return and to the most economical means of accomplishing it.

Effects of hardwoods on litter decomposition and soil qualities. -- Studies at the Crossett Experimental Forest (19) as well as common observation indicate that litter--whether it be pine, hardwood, or mixed--decomposes rapidly in the warm climate of the Crossett area. This is quite unlike the experience of northern Europe which tends to dominate the literature.

Stands high in certain hardwoods, particularly dogwood, often develop a loose spongy surface ( $A_1$  layer) that is presumably due to the activity of soil animals. Although the physical properties of such a layer are well suited for water entry and root growth, it does not necessarily follow that the surface layers under pine fail to provide aeration and infiltration adequate for optimum growth. Moreover, it appears that, under the natural stands of the area, growth is affected more by inherent differences in the permeability of the deeper soil layers than by surface variations. It is not enough to demonstrate that surface differences exist; it must be shown that they are of significance under field conditions. It does not seem likely that undisturbed soils of stands having greater and lesser mixtures of hardwoods with pine will develop such marked contrasts as have been found beneath various species in old fields (2, 32).

In other regions, mixtures of deep-rooting hardwoods with shallow-rooting conifers have been advocated. This consideration seems unimportant in the Crossett territory. The pines appear to root at least as deeply as most of the associated hardwoods. Much of the macropore system in the deeper layers of the soil beneath pine appears to consist of minute root channels or casts. Decay of the taproots provides massive channels extending downward from the surface; these are particularly common in young stands after thinning or mortality. Quite evidently the physical aspects of stand composition can be resolved only through measurements, particularly of moisture transmission, pore space, and aeration, in both surface and subsurface layers.

Stability of mixed stands. --Much of the discussion of stability relates to insect and disease problems outside the scope of this analysis. If a pathogen spreads by means of root contact, then admixture of a non-susceptible species may lessen the opportunity for new infection. Thus the use of hardwoods as barriers appears to have reduced the loss of spruce from Fomes annosus on old-field soils in Scandinavia. The usefulness of such measures for a particular pathogen is of course no argument for their general application.

"Stability" sometimes takes on a speculative aspect when applied to soil biology. The populations of various groups of soil organisms undergo great change with season, energy supply, and disturbance, but the overall processes leading to ultimate decomposition continue. For purposes of this program it seems justifiable to work with measurable physical and chemical soil changes in the expectation that these will reflect as well as determine microbial activities (42).

As with fire, the speculative effects of changes in composition are many, and the first task of investigation is to direct attention to the significant ones, if any. With a natural soil as a starting point any changes due to differences in composition almost certainly will require some years to become measurable, and the effects of such differences will not be the same on all soils.

The exploratory phase of this study, then, is to determine magnitudes and to indicate how much of a problem could actually exist. For example, an exploratory study might utilize such existing plots and natural groups or stands as show differences in composition unrelated to site. Although these would probably be unsuitable for growth measurements, differences in physical properties at various depths and gross annual nutrient return from all vegetation could be compared for effects of stand composition. Inasmuch as logging of the virgin forest occurred within the past 50 years, an effort to locate areas that formerly were pure pine (as compared with adjacent mixed wood on similar soil) might be successful. Comparative height growth of the young stands on such areas would represent a crude but long-term test of composition effects. Since calcium content tends to be characteristic of species it may be possible to use basal area calculations to estimate changes in litter content due to TSI.

Permanent plot studies probably will be necessary if for no other reason than demonstration. Plot studies of conversion to pure pine and pure hardwood, and of understory elimination, are already under

way on the Crossett Experimental Forest, and these can be used to great advantage. Additional long-term plot studies of simple design for measuring growth of pine in pure stands and in various mixtures can be established on major soil groups without heavy commitments of manpower. As indicated later (IV, B; IV, C), studies of fertility status, physical factors affecting growth, and possible modifications of both should have primary emphasis, for the results may outmode many of the present questions about stand composition. In the meantime, permanent plots may also provide some answers and, in any event, will afford valuable sites for studies of soil effects in the light of new concepts or findings.

## II, B. Fire effects

Studies of fire effects are needed, both to understand the influence of past burning on present site productivity and to evaluate this aspect of prescribed fire. Metz (28) and Burns (3) have summarized the literature on fire effects. It is evident that fire removes much of the surface organic layer, destroying the nitrogen content and releasing the ash elements to the soil surface to be reabsorbed or washed away. The removal also exposes the soil and changes the food supply and environment of organisms in the surface layers. Whether fire affects yields of timber depends very largely on the extent to which water entrance into the soil and the relative supply of available plant nutrients are changed. Existing studies on Coastal Plain soils (20, 23, 24, 41) show only minor effects.

When fire is frequent enough to keep the soil bare much of the time, physical deterioration may be rapid. Similarly the chemical losses from burning may be serious on coarse-textured soils. The conclusions from such extremes, however, cannot be applied to very different conditions of soil or burning frequency. Likewise the observations from other regions are of minor value as guides except as they demonstrate the considerable difficulties in obtaining conclusive results (3).

As already mentioned, exploratory studies are needed to point out which of the many possible variables are likely to be significant. It is useless to consider the possible effects of organic matter and nitrogen losses by fire, for example, when even the magnitudes of such losses are unknown. Similarly, the effects of single fires on infiltration and runoff on these soils are not known, although they can be measured experimentally, along with the rapidity of recovery after fire. Information of this nature can be obtained fairly rapidly and for various site conditions.

Permanent plots subjected to various burning treatments are almost essential, both as the ultimate tests of cumulative effects and as demonstrations. Very probably these can be made part of more general studies of management practices.

## II, C. Soil compaction

Investigations in agriculture (15, 43) have demonstrated that soil compaction by farm machinery may reduce yields markedly. The compaction effects often extend several inches below the wheel tracks and are cumulative in the soil beneath the plow layer. The resulting "traffic soles" or pans restrict root development. Vibration, as well as nominal pounds-per-square-inch loading, is presumed to be an important factor in their origin.

Within the Crossett area a few stands were observed that had been badly cut up by wet weather operations. The deep ruts necessarily mean root injury as well as compacted or puddled soil. Although only a fraction of the total surface is directly affected, the criss-crossing ruts may affect root spread and lateral movement of soil water. In areas where such rutting is severe it may prove more important to productivity than either controlled fire or hardwood reduction. The damage is likely to be prolonged, for the effects of both root decay and compaction may persist for some time.<sup>2/</sup>

The areas visibly affected are limited, of course, but are often the most accessible. Damage along skid roads and landings is presumably inescapable. Elsewhere track and multi-wheel equipment is less likely to produce deep ruts, although it may be capable of packing wet soil.

Exploratory study of these effects is suggested. The extensiveness and degree of compaction can be measured on small areas and related to known conditions for root development (27, 34). Growth responses can be studied by treatment of experimental plots or by comparisons of affected and non-affected groups within winter-logged areas. At least some observations of root injury and subsequent decay should be made. Such studies will indicate the extent to which further investigation may be justified.

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<sup>2/</sup> McCulley (48) has pointed out similar injury following wet-weather logging in Virginia.

### III. Site Improvement

As is known, agricultural crop yields have been increased greatly by soil drainage, fertilization, and similar measures. This has been done not only on "depleted" soils but also over large areas of land inherently low in productive capacity. It is perhaps instructive to note the reflection of F. J. Weis:

Until 1900 agricultural science was based on the idea of providing ideal natural conditions for the growth and reproduction of crops and livestock. Under such a theory, improvements upon nature were inevitably haphazard. In this century agriculturists have awakened to the possibilities of improving on nature, as indeed man has been doing ever since he began to till and cultivate. To work out systematically artificial means for obtaining the best possible yields--this is the new viewpoint represented by the term chemical agriculture. (Sci. American, August 1952)

By comparison, about the only means usually recommended for maintaining or increasing forest soil productivity have been through changes in stand composition. With a few notable exceptions, the employment and even the testing of more direct measures have been restricted by the low investments considered practical and by the limited responsiveness of some species and soil situations. The emphasis on moisture relationships as controlling factors has also lessened attention to fertility.

Nevertheless there are a number of instances in which artificial measures have increased growth under plantation or forest conditions. Thus forest drainage is common in Scandinavia and gives promise of considerable success in the Coastal Plain of the Southeast (1). Stunted red pine plantations on coarse sands in New York have been restored to near-normal growth by application of potassium (21). Second-growth hardwood stands in the Northeast have responded markedly to nitrogen (30), and nitrogen response of hardwood species planted with black locust has often been noted.

Such random examples can be multiplied, but they merely confirm that under certain circumstances growth can be increased by proper measures. The question thus becomes whether within this area site productivity can be increased by economically feasible means. As R. R. Reynolds has noted, a ten-foot increase in site index represents a volume sufficient to justify considerable investment. Accordingly, several exploratory stud-

ies should be directed towards first learning whether and under what conditions apparent site quality can be increased.

Care will be needed in selecting areas for study, since in many instances the physical nature of the soil profile may limit effectiveness of the treatment. Four possible lines of study are discussed below:

### III, A. Fertilization of plantations on old fields

The exceptional growth of planted seedlings in girdled areas as compared with that in old fields directs attention to the limiting factors on old-field sites. The physical properties of the deeper soil layers may have changed to some extent even in the absence of much erosion, and certainly the supplies of available plant nutrients have diminished. Thus one outcome of fertilization experiments would be at least a partial evaluation of the relative importance of these two groups of factors.

Observations within the Crossett area strongly suggest nitrogen deficiency in loblolly pine planted in many old fields. The possibility of response can be readily tested by direct fertilization and, if fertilization is successful, some thought could be given to other means, such as fertilized bands of lespedeza or blacklocust, of providing a more sustained nitrogen supply. Such means have proved successful with hardwood plantings on low nitrogen sites (45, 47). Such studies may be combined in part with the wide-spacing experiments contemplated by Reynolds at the Crossett Experimental Forest.

Although both observation and existing soil analyses emphasize the significance of nitrogen, the possibility of other limiting factors can be explored if warranted. Methods of predicting deficiency and response through tissue analysis (21, 30) can be developed in the course of the empirical fertilizer trials and will have wide utility.

### III, B. Fertilization of natural stands

In addition to exploring the possibility of increased yields these tests can materially increase knowledge of the factors limiting growth. Random trials with poor sites should be avoided. Instead, observations and analyses should be used to restrict treatment to the elements limiting growth and to soils of favorable physical properties.

Observations on the lesser vegetation of a few stands in the Crossett area suggest that nitrogen may sometimes be in short supply. This assumption can be tested by the foliar diagnosis guides mentioned

above and by direct fertilization. Such information on nitrogen status would be useful also in appraising the effects of burning.

### III, C. Stand composition

In some respects this is a variation of the question discussed under II, A, and the same general considerations apply. There is a notable difference in starting point, however, for the sites here considered for improvement by such means very commonly are eroded or "worn out" agricultural lands. The organic matter content is usually low and the physical properties are often impaired.

In at least some instances the surface layers of such soils undergo rather slow changes if occupied by pine, whereas the physical and chemical changes occurring beneath high calcium species appear much more favorable for water movement and plant growth (2, 7, 32). Such changes have directed attention to foliage composition and the activities of soil fauna. In general the effects upon growth and watershed values have not yet been demonstrated, but there is little reason to doubt that they occur and that species composition is important in the rehabilitation process.

Since rehabilitation of eroded agricultural land is not a widespread problem in the Crossett area, it seems advisable to leave investigation of this subject to other stations where it is already receiving attention (2, 29). The procedures devised will be of interest, however, and can be installed as tests or demonstrations on old-field sites in the Crossett area.

### III, D. Drainage

No specific proposals for drainage studies are made at this time. Tests under way, as on the International Paper Company land near Camden, and in the Southeast (1), should be watched closely. Observations during the course of the site classification study will give some indication of the area on which drainage measures might be feasible. Possibly road ditches and plowed fire lanes can be made to serve for drainage or interception under suitable conditions.

## IV. Basic Studies

As is evident from the foregoing, many problems involving the effect of a given factor or practice on site quality can be resolved only in the light of basic information on soil and tree characteristics. Without some

information of this kind, it may frequently be impossible to define complex problems sharply enough for efficient investigation; at best, solutions will be limited to those empirically derived.

The objective is to accumulate enough information about the principal species and soil groups to allow predicting their performance under existing conditions and estimating their probable response to treatment or environmental changes.

The outline that follows is in terms of the organized information wanted. The subdivisions are not mutually exclusive, and studies within one may often contribute to others. Much of the information will necessarily be obtained from studies conducted for specific objectives; almost any study, however empirical, can contribute if the basic information goals are considered in its design. Neither physiological nor watershed investigations are contemplated at this time, but both interlock with the studies outlined.

#### IV, A. Factors restricting root activity and soil utilization

It is evident that the amount of water or nutrients that a forest can obtain from a soil depends on two factors: the quantity recoverable from a given amount of soil, say a pound or a cubic foot, and the total number of pounds or cubic feet of soil subjected to root action. The water available per unit volume can be estimated from measurement, and available nutrients per unit volume or mass can be often interpreted from chemical analyses; in a general way both can also be inferred from soil texture. Often, however, such estimates acquire significance only when combined with some measure of the soil volume exposed to active roots.

The volume of soil used by the roots depends largely on the properties of the subsoil, and is limited particularly by mechanical resistance and lack of aeration (27, 34, 44). These last may be such as to wholly prevent root growth below shallow depths, as in some "prairies" and prairie margins. More commonly they restrict root development, confining roots to cleavage planes and other fissures and limiting root activity to only a part of the growing season. Such limitations exist in various degrees and undergo temporary increases or decreases in severity during a succession of unusually wet or dry years. Differential reactions of shortleaf and loblolly pine to moisture can be inferred from Turner (39) and the littleleaf studies (12, 22), but are not indicated by Coile's results (8).

Integrating the combined effects of soil moisture, nutrient availability, and factors affecting root activity or development is clearly difficult and reliance has had to be placed on estimates of profile drainage, texture, and consistence. Without doubt the empirical relationships of site index to drainage, texture, structure, and consistence, or to soil units in which these are combined, will continue to have wide use. Such relationships can be made more satisfactory, however, if they can be interpreted in terms of growth conditions.

Thus it is proposed to follow the site classification study (I) with one or more investigations in which the physical factors characterizing certain poor and mediocre sites will be measured. Since sites may be poor for any one of several reasons, they will have to be grouped according to the probable limiting factors. Likewise loblolly and short-leaf pine must be segregated. The effect of fertility differences between the poor sites and the best can either be tested or simply reduced by heavy fertilization, so as to leave physical factors dominant. The analysis should be concentrated on the factors significant for root development, principally aeration and pore space within the deeper layers, and the degree of water utilization. The time and extent of root development can be studied in relation to these. Measurements should continue long enough to indicate the effect of critical periods and seasonal extremes (36).

The results will lead to quantitative description of site quality in terms of root growing space and growth conditions. They may indicate the extent of site improvement possible, as through drainage, fertilization, species choice, etc. Finally they probably will be helpful in explaining instances of abnormally poor growth or mortality that seem related primarily to site rather than pathogens.

#### IV, B. The water regime

Differences in productivity among various soils are related in part to their capacity to supply water to the plant. In addition to adequate fertility and aeration, good sites are characterized by a considerable moisture-holding capacity, greater than average depth of penetrable soil, or additional surface or subsurface water. Further, in the absence of a water table or seepage, the extent to which water is removed from the soil is perhaps the best means of estimating the effectiveness of root penetration and hence of the utilizable volume of soil in which the tree also finds nutrients and anchorage.

The rate of water entry into the soil in the summer influences runoff and the moisture available for growth. Turner (39) attributed the lower site index of pine on steeper slopes to greater runoff, but Coile's more comprehensive analyses in the Southeast (8) indicated slope to be a minor factor except as it affected depth of surface soil. Decreased water intake is also one of the frequently cited effects of fire, erosion, and compaction.

Hence data on moisture additions, storage, and utilization are needed to understand growth effects and competition. Such data will fall into 3 classes: 1.--Estimates of infiltration, transmission, and runoff on various soil types and treatments. 2.--Estimates of stored water available to vegetation in various profile types; also description of the special cases where ground water is utilized through much of the growing season. 3.--Estimates of water use by trees, along with estimates of the effect of water deficiency on trees.

Some of this information will be provided by other programmed studies (see II, A and IV, A) or by collaborative studies (Vicksburg Infiltration Project, Southeastern Forest Experiment Station, Stephen F. Austin College, etc.). Ultimately, it is desired to account for the disposition of all precipitated water reaching either plant or soil. Such information would facilitate estimating how growth is affected by changes in infiltration rate or available moisture.

#### IV, C. Nutrient status

Under experimental conditions, soil fertility--unlike physical properties--can be manipulated with relative ease. Further, the analytical data are often less equivocal and are, in the main, susceptible to straightforward interpretation. Hence, in this phase, the gap between investigation of particular problems and the basic studies is relatively slight.

Information from the projected studies can be organized in terms of: 1.--Nutrient balance, the gains and losses to the forest as through leaf fall, fire, etc. 2.--Nutritional adequacy and response to fertilization.

A complete nutrient balance exists only as a schematic device, of course, but the concept will be useful as a means of presenting and evaluating analytical data, as from studies of leaf fall, and burning losses. In general, it is easier to obtain data of this sort than to determine their long-time significance. It will be found, however, that

the removal of wood and bark from high-yielding stands results in an appreciable annual nutrient loss.

The initial studies of fertilizer response and the standards of nutritional adequacy based on tissue or soil analysis will provide useful tools for other investigations. As tests of possible site depletion by cropping, repeated burning, or hardwood removal, such analyses may prove more sensitive than growth rate. Soils of similar physical properties but unlike productivity can be compared by these means. Differential responses of various species to fertility level will probably provide clues to hardwood competition and behavior.

The effort given to additional fertilization studies will depend on their practical implications.

#### IV, D. Soil distribution

Although the studies outlined under I and IV A relate tree growth to soil properties, they leave unanswered the question of where soils with the various properties occur. On some forest land holdings this will be met by specific classification or mapping systems, but it is doubtful that any large percentage of the area will be treated uniformly. If the relationships of soil to tree growth are to be widely applied, they should be associated with recognized soil units insofar as possible.

The conventional soil types embody many of the physical features significant for tree growth even though both mapping detail and the separations recognized may not fully coincide with the needs of forest management. In the absence of some alternative system applied generally to forest lands, however, the conventional soil types as now recognized may well serve as the best cheap criteria for efficiently stratifying land into areas of comparable potential forest productivity. A suitable basis of comparison will become increasingly important for evaluating results from the numerous management studies, and in studies of diseases, etc. (11, 22). Moreover, investigations of soil properties and productivity by agricultural experiment station workers will be linked to these types (9, 14, 31).

Unfortunately there are no modern soil surveys for the counties within the Crossett area. The existing surveys (40) are hopelessly antiquated, although some of the mapping boundaries are probably valid. Because of its small scale, the recent generalized soil association map is merely suggestive. When the utility and need of suitable soil maps in forestry have been demonstrated, however, it is very probable that as-

sistance can be obtained from the Division of Soil Survey and the State Agricultural Experiment Stations. Revision of the older county surveys, even as association maps, together with possible use of the Soil Conservation Service capability maps and additional reconnaissance mapping, should provide, as a minimum, a satisfactory large-scale generalized map of the area.

## PRIORITIES

A statement of priorities can be only tentative, for we have an incomplete knowledge of soil problems and future management practices; it will need revision as the program progresses. Priority is partly a matter of emphasis rather than strict precedence, for field studies are often long in maturing and several may be carried on simultaneously.

Primary emphasis should be placed on a site classification study. The results will have immediate use in practice and, as noted, observations made during the study will be valuable in subsequent investigations. Allowing for orientation and interruptions, about two years should be allocated to this study.

Investigations of site quality reduction through fire or hardwood removal will be long in yielding conclusive results. At present there is no actual evidence demonstrating deterioration by either. Further, the attention given to fire depends in part on an estimate of its future place in forest management. Although long-term plot studies are advisable, we should also take advantage of existing and contemplated plots installed for other purposes. Their selection and initial measurement might well begin before completion of the classification study. The other aspects should follow its completion except as opportunities for cooperative work may arise sooner. In the beginning, preference should be given to the type of exploratory study mentioned rather than to long-term commitments in plot maintenance and analytical work.

Following the classification study and the initial phases of the site deterioration study, investigations of soil aeration and moisture in relation to growth should be developed strongly. Information from these and the fertility experiments may answer fears of site deterioration sooner than actual plot studies.

The acreage of plantations in the Crossett area is not large but such planted old fields as do occur will be useful in exploratory fertility trials. These may be started immediately but on a modest scale. The

results will indicate to what extent this line of investigation should be developed. The study of soil compaction likewise will require relatively little time for the exploratory phases, which may be started whenever suitable equipment is available.

Needs for additional studies not presented here will probably arise. Thus, root diseases or root competition might demand greater attention than has been indicated. In general, however, there should be a reluctance to undertake studies merely to characterize soils, to make profile analyses not correlated with tree growth, or to comply with current enthusiasms. The influence of soil fauna, for example, is of interest in connection with soil structure but to identify more than a few organisms would require the services of a competent invertebrate zoologist. Adequate studies of the ecology of soil fauna would demand greater resources than this program is likely to have available. Similarly, soil microbiology has progressed so far that no serious investigation is possible without specialized personnel.

No single program can hope to investigate all of the soil variables of possible importance. For this reason close association and interchange with other soils investigators and with agricultural workers in the region are essential. Work under way by the East Texas Branch and the Vicksburg Infiltration Project of the Southern Forest Experiment Station and by the Central Piedmont Branch of the Southeastern Station--including the littleleaf investigations--bears directly on some of the proposed studies. There should be a continuing effort to avoid duplication. Cooperation with the forest schools and with agronomists and soil scientists, particularly the soil surveyors and physicists, will be necessary since their work is basic to many of the applied studies contemplated.

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